UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC DOWNPULL STUDIES OF THE FIXED-WHEEL SPILLWAY GATES FOR RED BLUFF DIVERSION DAM CENTRAL VALLEY PROJECT, CALIFORNIA

Hydraulics Branch Report No. Hyd-511

DIVISION OF RESEARCH

OFFICE OF CHIEF ENGINEER
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Division of Research
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Subject: Hydraulic downpull studies of the fixed-wheel spillway gates for Red Bluff Diversion Dam--Central Valley Project, California

PURPOSE

Studies were conducted to determine the downpull forces on the 60-foot-long by 18-foot-high upstream seal, bow truss, wheel-mounted spillway gate during free and submerged discharge operation.

CONCLUSIONS

Conclusions Based on Preliminary Tests and Investigation

1. The buoyant characteristics of the gate were determined with respect to depth of submergence (Figure 10). This relationship is complicated because of the structure of the gate.

2. Surface tension did not interfere in the measurement of vertical forces on the model gate during flow tests because the oscillating water surface tended to average out tension forces.

3. Vibration phenomena cannot be scaled from the model because the equivalent gate mass was not represented in the model and it was impossible to scale all forces applied to the vibrating system.

Conclusions Based on Fixed-mode Tests

1. The coefficient of discharge of this gate was conveniently expressed as a function of the headwater parameter (H_1/b) and the tailwater parameter (H_2/b). The interrelationship of these parameters as determined from the model is shown in Figure 11A.

2. The submergence characteristics of the gate are given in dimensionless form in Figure 11B. In this plot the submergence parameter (S/b) is related to the tailwater and headwater parameters.

3. The pressure head on the bottom of the gate lip is equal to the submergence head at the downstream face of the gate. This phenomenon is clearly demonstrated in Figure 11C.

4. Using the relationship as stated in Paragraph 3, the lip pressure head coefficient $\left(\frac{H_1 - S}{P_{avg} - b}\right)$ was computed. The interrelationship of this coefficient with respect to the headwater and tailwater parameters is given in Figure 11D.

5. The combined vertical forces of buoyancy and gate lip pressure were computed and plotted as solid lines in Figure 12. The effects of truss drag, skinplate drag, slot jetting, and compartmentation of air or water cannot be determined from the fixed-mode data.

<u>Conclusions Based on Freely Suspended Mode Tests</u>

1. Horizontal forces, as measured, agreed closely with those normally computed by designers.

2. Slot jetting had considerable influence upon the magnitude of the total vertical forces on the gate and was highly sensitive to headwater, gate opening and submergence. Forces from slot jetting can be either uplift due to impingement on the underside of the web membranes or downpull due to compartmentation of water on top of the web membranes.

3. The slot jetting was caused mostly by the expansion and deflection of the main flow into the slot region below the gate lip rather than by leakage necessary to keep the gate free and floating for vertical force measurements.

4. Comparison of the fixed-mode data with the floating-mode data in Figure 12 shows that the net result of slot jetting contributes uplift. The two sets of curves in Figure 12 shows that maximum downpull will occur during unsubmerged flow.

5. The maximum downpull force for the design head of 18 feet, measured by the weighing method was 13, 000 pounds at a gate opening of about 5-1/4 inches prototype and occurred at free discharge (Figure 15).

INTRODUCTION

Red Bluff Diversion Dam is on the Sacramento River in the Central Valley Project, California, and is located about 2 miles downstream from the town of Red Bluff (Figure 1). The dam will control the upstream water surface elevation by means of 10 spillway gates 18 feet high and 60 feet long (Figure 2).

The nature of the river downstream from the dam is such that at large flows the water surface will be above the spillway crest and will back up and submerge the gates. An upstream seal gate of conventional design with solid web beams would experience large downward forces during submerged operation because of the pressure differential resulting from reduced pressures under the lower beam due to the flowing water and positive pressures above the beam due to tailwater. Similarly, large downpull forces would be experienced with a downstream seal gate of conventional design for this installation. Large downpull forces were undesirable because of the extra costs for gate handling equipment, hoists, cables, and operating bridges.

An unusual design was adopted for the gates using an upstream skinplate and seals, and open, free-draining trusses made of 2-7/8- and 2-3/8-inch-outside-diameter pipe on the downstream side (Figure 3). This construction was expected to greatly reduce the downpull forces when the tailwater is high enough to cause submerged flow.

For design purposes it was necessary to know the magnitude of the downpull forces. An analytical evaluation would necessarily involve a number of unknowns and would be uncertain. An hydraulic model study on a 1:18.6 scale was therefore conducted.

Because of the unique design of the gate and the expected submerged flow condition, a weighing technique was used to determine the overall forces. Piezometric pressure measurements at selected points permitted separating those forces due to the lip and bottom seal from those of other sources.

ACKNOWLEDGMENTS

The results achieved during this study were the direct outcome of close cooperative efforts between the Mechanical Branch, Division of Design, and the Hydraulics Branch, Division of Research, of the Chief Engineer's Office in Denver.

THE MODEL

Selection of Model Scale

The model scale was selected to keep the discharges within a convenient range of laboratory pump capacity and to provide a large enough gate for good hydraulic similitude. The determination of the drag forces on the pipe-truss members and the separation of these forces from the lip seal forces was considered the key to the study. The exact value of 1:18.6 was determined by these considerations, and by the dimensions of the telescoping brass tubing available for modeling the truss-pipe members.

Gate

The gate was fabricated using galvanized sheet steel to form tee sections, angle iron bracing, the lip seal, and the skinplate. Hard-drawn brass tubing, sealed at their ends, represented the pipe members of the trusses (Figures 4 and 5). Only the three lower trusses were built in the model gate because the tailwater would never rise high enough to affect higher trusses. Wheels, which would not significantly influence the downpull forces, were omitted. All other pertinent members such as deflector plates, stiffeners, etc., were included on the gate. Four piezometers were placed in the gate bottom, or lip seal, to determine pressures acting under this surface (Figures 4 and 5). Solid plate web members are at the slot ends of the gate. These members, in conjunction with the tee flanges and vertical end plates, form compartments which could trap water or air. To prevent this possibility, drain holes were drilled as shown in Figure 4.

Flume and Head Box

A 25-foot-long flume, 20 inches deep and 44 inches wide, was used to represent approach and downstream conditions for 1 bay of the 10-bay spillway. The flume was constructed of 2- by 4-inch framing and 1-inch siding. The flume was lined with sheet metal to make it watertight, and was equipped with suitable piping and an 8-foot wide by 8-foot long by 5-foot 8-inch deep head box to provide good flow conditions (Figure 6).

Piers and Overflow Spillway Crest

Since the model represented one bay of the prototype, half piers made of waterproofed wood were installed at each end of the bay, Figure 6. The portion of the overflow spillway above elevation 230.00 feet was represented in the flume and was formed of concrete. The prototype drawing of the overflow weir and piers appears in Figure 7.

INSTRUMENTATION AND TECHNIQUE

Suspension System

Generally, in gate downpull studies, the method of pressure determination by piezometers is preferred over the weighing technique. This preference is due to difficulties in accounting for mechanical friction forces of rollers, wheels, seals, and for leakage if the gates are lifted clear of the tracks. However, the determination of the total vertical forces by pressure readings was considered virtually impossible for the Red Bluff gate because of the open trusses reinforcing the gate. Therefore, the weighing method was selected and pressure measurements were obtained at selected points on the gate for certain additional information.

The weighing system included a horizontal flexure bar, rigidly supported at the center and connected to the gate at the ends, and strain gages to measure flexural deflections (Figure 8). The entire weighing system could be lowered or raised by means of threaded rods and nuts to adjust the gate opening.

The flexing bar was milled from a 40-1/4- by 2- by 3/4-inch brass bar. The length of each cantilevered end of the bar was 13-3/8 inches and was milled down to one-fourth inch. At the fixed ends of the cantilevers were two 120-ohm, 1/4-inch bonded strain gages; one was attached on the top surface and the other on the bottom surface of the flexing arm. The four strain gages were connected in an external four-way additive and self-temperature compensating bridge and connected to one channel of a recorder. A switching circuit was devised so that readings of each arm could be recorded separately in half-bridge circuits in two other channels of the recorder using internal dummies. The bridge and switching circuits are shown in Figure 9A.

The brass flexing bar and the bonded strain gages were found to be linear with respect to applied weight. The system was calibrated so that 1 pound of vertical force deflected the stylus 10 mm on the recorder chart.

To assure that the gate was not in contact with the gate tracks or projecting seal seats during weighing (Detail P, Figure 6), a horizontal harness system was developed. This system consisted of tensioned piano wires attached at the wheel point elevations of the gate. The wires were kept horizontal and in line with wheel elevations by adjustable pulleys mounted in the head box (Figure 6). The horizontal tension in the wires was adjusted to hold the gate in an upstream position, but just free from contact with the projecting seal seats. This placed the gate in its normal operating plane and avoided friction forces.

To measure wheel loads of the gate, a brass tube was inserted in the main wire of each horizontal harness system. Four 120-ohm, 1/4-inch bonded strain gages were attached to each tube. The gages were paired off at 180° and connected in series. Dummy gages were made in the same manner and were placed in the head box so that they would not be strained, thus compensating for temperature. The pairs of gages were connected into a bridge circuit as shown in Figure 9B. Since the individual members of the pairs of gages were placed 180° with respect to each other, the measuring system was compensating in regard to bending forces on the tubes. The tubes were calibrated so that 1 pound of horizontal force would deflect the stylus 0.8 mm on the recording chart.

Discharge Measurements

Discharge measurements were obtained by means of a calibrated venturi meter bank which is an integral part of the permanent hydraulic laboratory installation.

TESTING PROGRAM

General

Before installing the model gate in the flume, preliminary measurements and investigations were conducted. The buoyant force on the gate was measured for the range of submergences included in the study. The effect of surface tension was investigated for scaling interference. The possibility of scaling vibration phenomena from this particular model was also investigated.

After the preliminary measurements and investigations, the gate was installed in the flume and two basic modes of testing were conducted. One mode was with the gate fixed or wedged into its normal upstream position within the gate slot. Hydraulic characteristics, such as coefficient of discharge, lip pressure, and depth of submergence were determined with the gate fixed at various gate openings (Table I). The other mode was with the gate freely suspended on the harness system in a manner so that vertical and horizontal forces on the gate could be measured without interference of bearing or seal friction forces. Care was taken to insure that the gate was not allowed to move downstream far enough away from the seal seat projections to allow excessive flow around the sides. Data obtained in this manner are compiled in Tables II and III.

Preliminary Tests and Investigations

Buoyancy determination. There are three common methods of determining the buoyant force characteristics of a gate. The first is a detailed computation of the volume of the structural parts of the gate. This method would be cumbersome for the Red Bluff gate. The second is to actually weigh the gate in air and at various degrees of submergence. The third is to measure the volume of water displaced at various depths of submergence. The volume displacement method was selected because of convenience and small influence of interfering factors such as surface tension.

The volume of water displaced by the gate at various depths of submergence was determined by a pressure cell that was calibrated to trace the volume of water displaced as the gate was slowly lowered into a tight-fitting prismatic tank. A wetting agent was added to the water to reduce the surface tension effects. A continual record of the gate elevation was concurrently obtained by a linear potentiometer geared to the gate. The buoyant force was then computed from the volume of displaced water and was plotted versus the depth of submergence (Figure 10).

Consideration of surface tension. In the preliminary stages of this model study, surface tension was expected to have significant effects on the vertical force measurements of the model gate. Surface tension was significant for measurements obtained with the water surface static or for the condition when the water surface was continually moving in one direction with respect to the gate trusses. However, when flow is passing through the trusses, as it will in the Red Bluff gates, the water surface is continually oscillating. This surface fluctuation causes the surface tension force on any part of the gate to oscillate between receding and ascending regimes, resulting in negative and positive forces. If the water surface oscillation is symmetrical with respect to the mean water surface elevation, the positive and negative surface tension forces are nullified. This condition prevailed in the tests and surface tension forces were not a significant factor.

Consideration of vibrations. The possibility of undesirable vibrations is of concern in the design of a gate. It is impossible or extremely difficult to predict by design calculations the magnitudes of the vibration forces in a structure as complex as these gates. Two types of vibration are possible; vibration of the gate as a unit, and vibration of individual gate components. In most studies, component vibration is not considered. When vibration as a unit is considered, the mass of the system must scale as the cube of the length ratio and the spring constant of the vertical suspension system must scale as the square of the length ratio. The sum of the mass of the model gate and flexing bar could not be scaled because of the limitations of materials for fabrication. A further hindrance to scaling was the necessary absence of guide rollers, the flap-type gate seals, and wheel friction during weighing. For the Red Bluff gate studies, therefore, the possibility of scaling of vibration was sacrificed.

Another source of scaling discrepancy is the problem of scaling viscous dampening. This problem is accentuated by submergence of the pipe members of the bow trusses. A Reynolds correction must be interjected into the study in order to scale viscous dampening forces. Consequently, no inference of the response of the prototype gate to flow induced oscillations can be made from the model gate. However, no troublesome surging of the flow was observed visually nor detected during piezometer readings.

Fixed-mode Tests

The hydraulic characteristics of the gate were determined from analyses of the fixed-mode model data in terms of dimensionless parameters (Figure 11).

These parameters were C_d, H_1/b, H_2/b, S/b, and $\left(\frac{H_1 - S}{P_{avg} - b}\right)$.

The coefficient discharge, C_d, is defined by:

$$C_d = \frac{Q}{bB\sqrt{2gH_1}} \qquad \ldots(1)$$

where Q is the discharge, b is the gate opening, B is the crest length or width between piers, g is the acceleration of gravity, and H_1 is the depth of headwater with the crest as the datum and measured one bay width upstream from the skinplate.

The parameter, H_1/b, is called the "headwater parameter," H_2/b is designated the "tailwater parameter," where H_2 is the tailwater depth above the crest measured two bay widths downstream from the skinplate. S/b is called the "submergence parameter" where S is defined as the depth of water above the crest at the downstream face of the skinplate. The ratio $\left(\frac{H_1 - S}{P_{avg} - b}\right)$ is the "lip pressure head coefficient" where $(P_{avg} - b)$ is the average pressure head on the bottom of the gate lip and (P_{avg}) is the average piezometric pressure on the gate lip with the overflow crest at the datum.

Coefficient of discharge. The coefficient of discharge for free-flow conditions, as defined by Equation (1), follows the upper dashed lined curve in Figure 11A. However, for submerged flow conditions C_d becomes a function of both the headwater and tailwater parameters, H_1/b and H_2/b and takes the form of a series of curves (Figure 11A).

Submergence parameter. Because the buoyancy of the downstream structural members was to be separated from the other vertical forces, the relationship of submergence on the downstream face of the gate with respect to the headwater and tailwater had to be determined. To do this, the headwater parameter H_1/b was plotted versus the tailwater parameter H_2/b with the submergence parameter S/b as the third variable (Figure 11B). The 45° line passing through the origin represents the no-flow condition when the three parameters are equal to each other. The determination of the condition of when free discharge is first attained as the submergence approaches a value equal to the gate opening is difficult because of the fluctuating water surface in the downstream roller. Therefore, a shaded parabola was used and designated as S/b approximately equal to one. Any combination of H_1/b and H_2/b below the shaded parabola represents a definite free-flow condition.

Interrelationship of submergence and pressure head on lip. Early in the fixed-mode testing program, it was noted that the pressure heads on the gate lip were nearly equal to the depth of submergence on the downstream face of the skinplate. To substantiate this observation, average values of the pressure head were computed and plotted in the form of $(P_{avg} - b)$ versus $(S - b)$ (Figure 11C). The plot clearly demonstrates that the downstream submergence and the pressure head on the gate lip are equal and identical for the Red Bluff gate.

Lip pressure head coefficient. It was assumed that the pressure head coefficient is a function of the headwater and tailwater parameters, i. e.,

$$\frac{(H_1 - S)}{(P_{avg} - b)} = \phi\left(\frac{H_1}{b}, \frac{H_2}{b}\right) \qquad \ldots (2)$$

This assumption was verified directly from the model data. However, since it was previously established that $(S - b)$ is equal to $(P_{avg} - b)$, values of H_1/b were computed and plotted for assumed values of S/b and pressure head coefficient (Figure 11D). Values of H_2/b were determined from Figure 11B. The 45° line passing through the origin represents zero pressure head coefficient or the no-flow condition. The zone of definite free flow is below the shaded parabola.

Forces that can be determined from fixed-mode tests. At this stage of the study it was possible to compute the resultant vertical forces on the gate due to buoyancy and lip pressures for any combination of headwater, gate opening, and submergence. The headwater was used to compute the force on the top of the gate lip projection. The amount of submergence was determined by using the gate opening and headwater in conjunction with Figure 11. The submergence head, being equal to the bottom lip pressure, was used to compute the vertical force on the gate lip seal. The difference of absissa between the two curves in Figure 10 was used to determine buoyant forces due to structural members on the downstream face of the gate. These computations were done for arbitrary gate openings of 1.65 and 2.58 feet prototype and plotted in Figure 12 as examples of how the combined forces of the gate lip and buoyancy vary with respect to submergence. The curves of these computations are shown as solid lines.

It should be noted that other information is needed to truly evaluate the vertical forces on the gate. In the fixed-mode tests other possible sources of vertical forces have not been taken into account. These are deflection of flow from the gate slot, drag on the skinplate, drag of downstream roller passing through bow trusses and compartmentation of air or water in or on parts of the gate structure.

To more fully evaluate vertical forces on a complicated structure like Red Bluff Diversion gate it was necessary to use the weighing technique in which the gate was freely suspended so that the total vertical force could be measured.

Freely Suspended Mode Tests

Horizontal forces on gate. In the earlier stages of the freely suspended mode tests it was noted that the measured horizontal forces agreed closely with those normally computed by designers. Any differences between the measured and computed values could reasonably be attributed to sealing differences between the prototype and model and to model measuring devices which are discussed subsequently under "Evaluation of Instrumentation and Technique." Consequently, no analyses of horizontal forces are presented in this report.

Effect of slot jetting on vertical force measurements. Slot jetting had considerable influence upon the resultant vertical forces measured on the model gate. Therefore, it was necessary to establish qualitatively the difference in jetting in the model when the gate was floating in the slot and when it was completely sealed on the upstream face as is the case for the prototype. It was questioned whether the jetting in the model was caused more by the leakage necessary to keep the gate floating so that downpull could be measured, or caused more by the expansion and deflection of the main flow in the slot below the gate lip. To obtain a better insight of the jetting action, the model was operated at two gate openings in the free-flow condition. For both openings the headwater elevation was maintained at 18 feet. For each of the gate openings, closeup photographs were taken of the downstream slot region for three conditions of sealing, Figures 13 and 14. The first condition was with the gate freely suspended in the slot and just clearing the slot seal projection; the second condition was with the gate pulled upstream with the skinplate fixed against the seal projection; and the third was with the gate fixed against the projection and completely sealed with modeling clay.

The photographs clearly show that for a gate opening of 2.6-foot prototype, the jetting action in the slot region is essentially the same for all three conditions of sealing. However, for the smaller gate opening (1.2-foot prototype), the deflected jet was impinging upon the underside of the bottom truss web membrane slightly more than when the gate was floating in the slot than when fixed or when fixed and sealed. There are other combinations of headwater, gate openings, and submergence where part of the deflected jet folded around the end of the gate and collected on top of the web membranes in the compartments at the slot ends of the gate.

During the course of both the fixed and freely suspended mode tests, it was found that the variation in jetting action was highly sensitive to the headwater, gate opening, and submergence. These factors predominated over the condition of sealing.

Submerged vertical force measurements. To obtain a better insight of the effect of the sources of vertical force that could not be measured by the fixed-mode tests, freely suspended mode data were obtained for the same gate openings and range of submergences that were plotted from fixed-mode data (Figure 12). These sources are, slot flow, skinplate drag and compartmentation of air or water. The freely suspended mode data points were also plotted in Figure 12 and their curve trend denoted by dashed lines. Comparison of the two modes of testing shows that the freely suspended mode data are offset in the uplift direction. Therefore, contrary to expected results the drag of the downstream roller passing through the bow trusses was minor relative to uplift caused by the deflected slot flow impinging on the underside of the web membrane. Furthermore, the two sets of curves show that downpull continually increases as the flow conditions approach free discharge and maximum downpull would occur at some gate opening during unsubmerged flow.

Free discharge vertical force measurements. Runs were made to determine the gate opening that results in the maximum downpull force on the gate for free discharge conditions. The gate was set to represent a 1.16-inch prototype opening and the discharge was adjusted until the headwater was at the design operation level. The horizontal tensioning was adjusted to assure that the gate was just free of the slot seal projection and the measurement of the downpull was recorded. The gate opening was increased in 2.33-inch prototype steps, the water surface was maintained at full operating head, and records were made of the vertical force. The results of these tests are in tabulated form in Table III and as a curve of gate opening versus vertical force (Figure 15).

Maximum downpull. The maximum downpull occurred with free-discharge conditions and was about 13,000 pounds. This downpull occurred at an opening of about 5-1/4-inch prototype.

EVALUATION OF INSTRUMENTATION AND MODEL TECHNIQUE

The instrumentation and model techniques were adequate for obtaining the information desired from the model study. However, they were cumbersome and time consuming for small openings and/or for small submergences. The source of the most trouble was the difficulty of maintaining the gate in a stable floating condition while headwater was being adjusted and while measurements were being obtained. It is recommended that in future studies of this type that a thorough survey be made of the present knowledge of the use of air as in "almost frictionless" bearings and "near surface vehicles." By this means, dependency on horizontal wires might be eliminated. The air jets could possibly be designed to prevent undesirable water leakage that might effect vertical force measurements. Ease and fineness of adjustment might be increased by valve controls on the air supplies. In the event horizontal wires are necessary, consideration should be given to using four parallel wires, thereby giving a parallelogram-type movement as the gate shifts from side to side rather than the pivoting movement obtained with the yoke and two-wire system used in this study (Figure 6).

The flexing bar and its strain gages worked very well for measuring vertical forces. However, changing the gate opening was cumbersome. This fault could be overcome by quick-acting and syncronized powered raising and lowering mechanisms.

The horizontal strain gage tubes used to measure wheel loads on the gate worked satisfactorily provided great care was taken in assuring that no torsion was applied to the strain gage tubes during measurements. The strain gages were arranged to be compensating for bending and for temperature.

The Sanborn multichannel recorder operated satisfactorily during this study. However, better use could have been made of it, and more complete data could have been obtained if additional automatic equipment had been available. As an example, downpull readings were taken with the gate set at specific, essentially fixed openings. Average values of downpull were obtained visually from the record charts, and a plot of downpull versus openings was developed. A better system would have been to continually move the gate through opening and closing cycles, maintaining appropriate head and discharge conditions by automatic controls, and obtaining readouts from data averaging electronic equipment. In this manner, very accurate, descriptive, and complete downpull histories would be relatively quickly obtained.

APPENDIX

Table I

FIXED MODE MODEL DATA
Hydraulic Properties of Gate

b* (in.)	Q (cfs)	H_1 (ft)	H_2 (ft)	P_{avg} (ft)	S (ft)	C_d -
0.30	0.327	0.999	0.451	0.423	0.423	0.505
0.30	0.328	0.928	0.381	0.357	0.351	0.525
0.30	0.329	0.863	0.318	0.280	0.280	0.546
0.30	0.330	0.742	0.199	0.158	0.155	0.591
0.56	0.762	1.030	0.270	0.197	--	0.620
0.56	0.400	0.910	0.660	0.659	--	0.348
0.56	0.400	0.655	0.420	0.403	--	0.409
0.56	0.400	0.510	0.280	0.257	--	0.463
1.20	1.090	1.078	0.691	0.653	0.650	0.405
1.20	1.095	0.889	0.511	0.452	0.455	0.448
1.20	1.097	0.799	0.425	0.359	0.358	0.474
1.20	1.100	0.679	0.318	0.243	0.235	0.515
3.00	2.00	0.415	0.325	0.239	--	0.465
3.00	2.00	0.575	0.440	0.376	--	0.407
3.00	2.00	0.703	0.550	0.496	--	0.368
3.00	2.00	0.855	0.690	0.645	--	0.334
3.00	2.00	0.980	0.810	0.775	--	0.312
3.00	4.30	1.170	0.460	0.264	--	0.614
3.00	1.00	1.050	1.010	1.010	--	0.151
3.00	1.00	0.863	0.790	0.787	--	0.169
3.00	1.00	0.660	0.620	0.611	--	0.190
3.00	1.00	0.460	0.435	0.424	--	0.228
0.400	0.348	0.985	0.560	0.539	0.540	0.409
0.400	0.348	0.815	0.390	0.361	0.363	0.450
0.400	0.348	0.690	0.270	0.236	0.233	0.490
0.400	0.346	0.588	0.170	0.127	0.130	0.523
0.780	0.736	1.050	0.613	0.569	0.575	0.426
0.780	0.736	0.885	0.453	0.401	0.400	0.465
0.780	0.742	0.770	0.345	0.285	0.283	0.502
0.780	0.742	0.682	0.260	0.197	0.200	0.533
5.00	6.25	1.015	0.585	0.423	--	0.576
5.00	3.00	1.085	0.970	0.932	--	0.267
5.00	3.00	0.900	0.800	0.760	--	0.292
5.00	3.00	0.740	0.658	0.603	--	0.323

Table 1--Continued

b* (in.)	Q (cfs)	H_1 (ft)	H_2 (ft)	P_{avg} (ft)	S (ft)	C_d -
0.60	0.605	1.030	0.561	0.530	0.530	0.460
0.60	0.607	0.944	0.464	0.427	0.425	0.482
0.60	0.609	0.841	0.377	0.327	0.330	0.512
0.60	0.611	0.740	0.275	0.219	0.215	0.550
0.60	0.614	0.720	0.250	0.211	0.200	0.559
1.00	1.03	0.600	0.238	0.087	--	0.617
1.00	1.03	0.800	0.372	0.311	--	0.533
1.00	1.03	0.953	0.515	0.464	--	0.488
1.00	1.02	1.050	0.610	0.565	--	0.462
1.00	1.42	1.040	0.280	0.090	--	0.645
1.00	0.440	0.210	0.160	0.121	--	0.446
1.00	0.440	0.435	0.348	0.344	--	0.308
1.00	0.440	0.580	0.495	0.486	--	0.268
1.00	0.440	0.740	0.650	0.656	--	0.236

*See definition sketch, Figure 11, for symbol definitions.

Table II

FREELY SUSPENDED MODE DATA
Vertical Force on Gate during Submerged Flow
$^{*}H_1$ = 18-foot prototype

Model			Prototype		
Gate open 1.66 (in.)			Gate open 2.58 (ft)		
*S	Vert. force		*S	Vert. force	
	Uplift	D. pull		Uplift	D. pull
(in.)	(lb)	(lb)	(ft)	(lb)	(lb)
7.38	0.98	-	12.1	6,310	-
9.35	0.75	-	14.5	4,830	-
7.30	0.70	-	11.3	4,500	-
6.95	0.60	-	10.8	3,860	-
6.15	0.75	-	9.5	4,830	-
5.90	0.65	-	9.1	4,180	-
5.40	0.40	-	8.3	2,570	-
5.15	0.45	-	8.0	2,900	-
4.55	0.52	-	7.1	3,350	-
4.00	0.30	-	6.2	1,930	
3.65	-	0.10	5.7	-	643
3.70	-	0.10	5.8	-	643
3.15	-	0.20	4.8	-	1,290
1.65	-	0.40	2.6	-	2,570

Model			Prototype		
Gate open 1.01 (in.)			Gate open 1.65 (ft)		
*S	Vert. force		*S	Vert. force	
	Uplift	D. pull		Uplift	D. pull
(in.)	(lb)	(lb)	(ft)	(lb)	(lb)
7.5	1.10	-	11.6	7,080	-
6.8	0.75	-	10.5	4,630	-
6.5	0.56	-	10.0	3,600	-
5.6	0.90	-	8.7	5,790	-
5.4	0.68	-	8.4	4,380	-
5.4	0.72	-	8.4	4,630	-
4.9	0.38	-	7.6	2,440	-
3.65	0.40	-	5.7	2,570	-
3.75	0.15	-	5.8	965	-
2.30	-	0.29	3.6	-	1,870
1.01	-	0.30	1.6	-	1,930

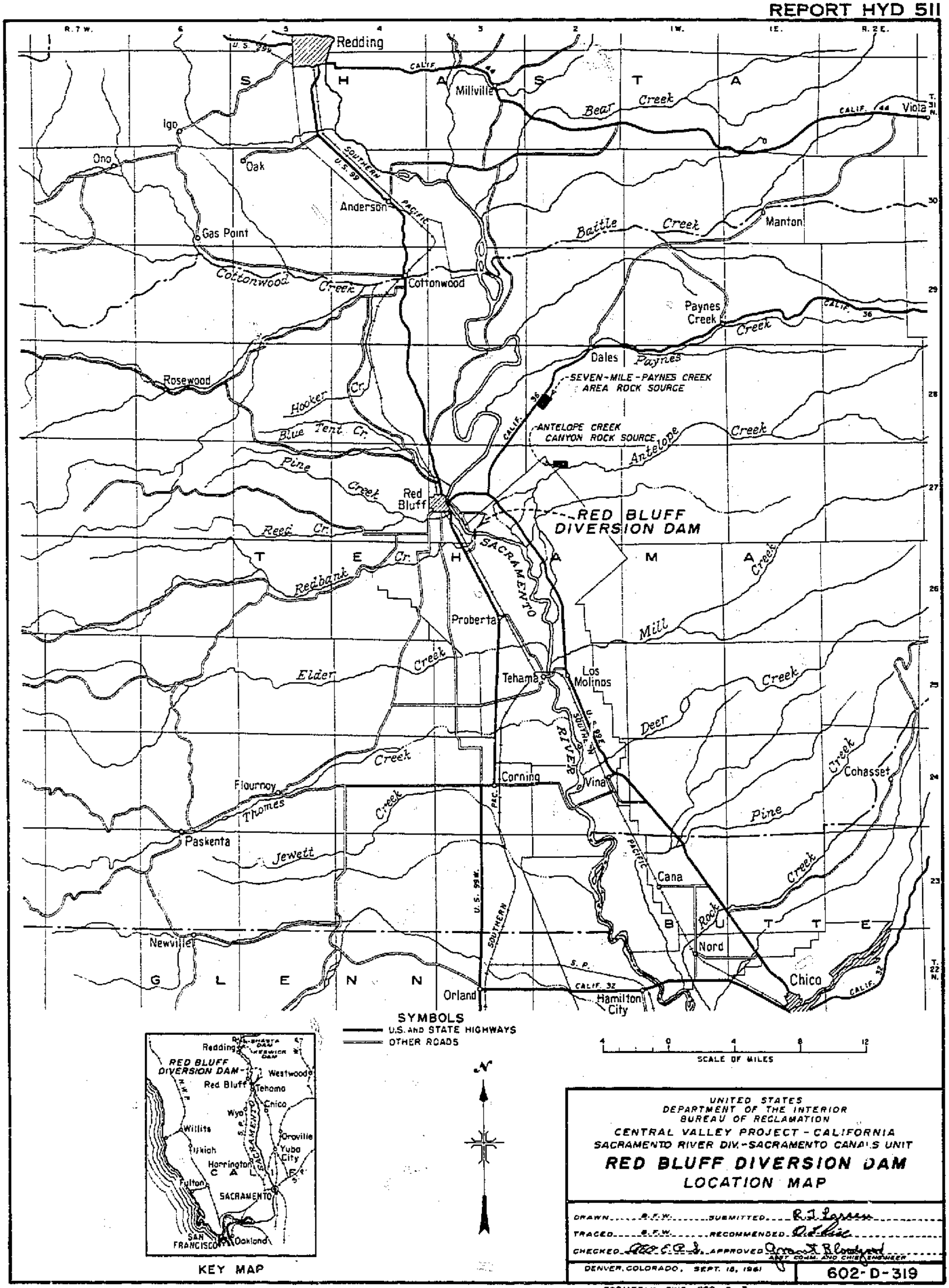
*See Figure 11 for symbol definitions.

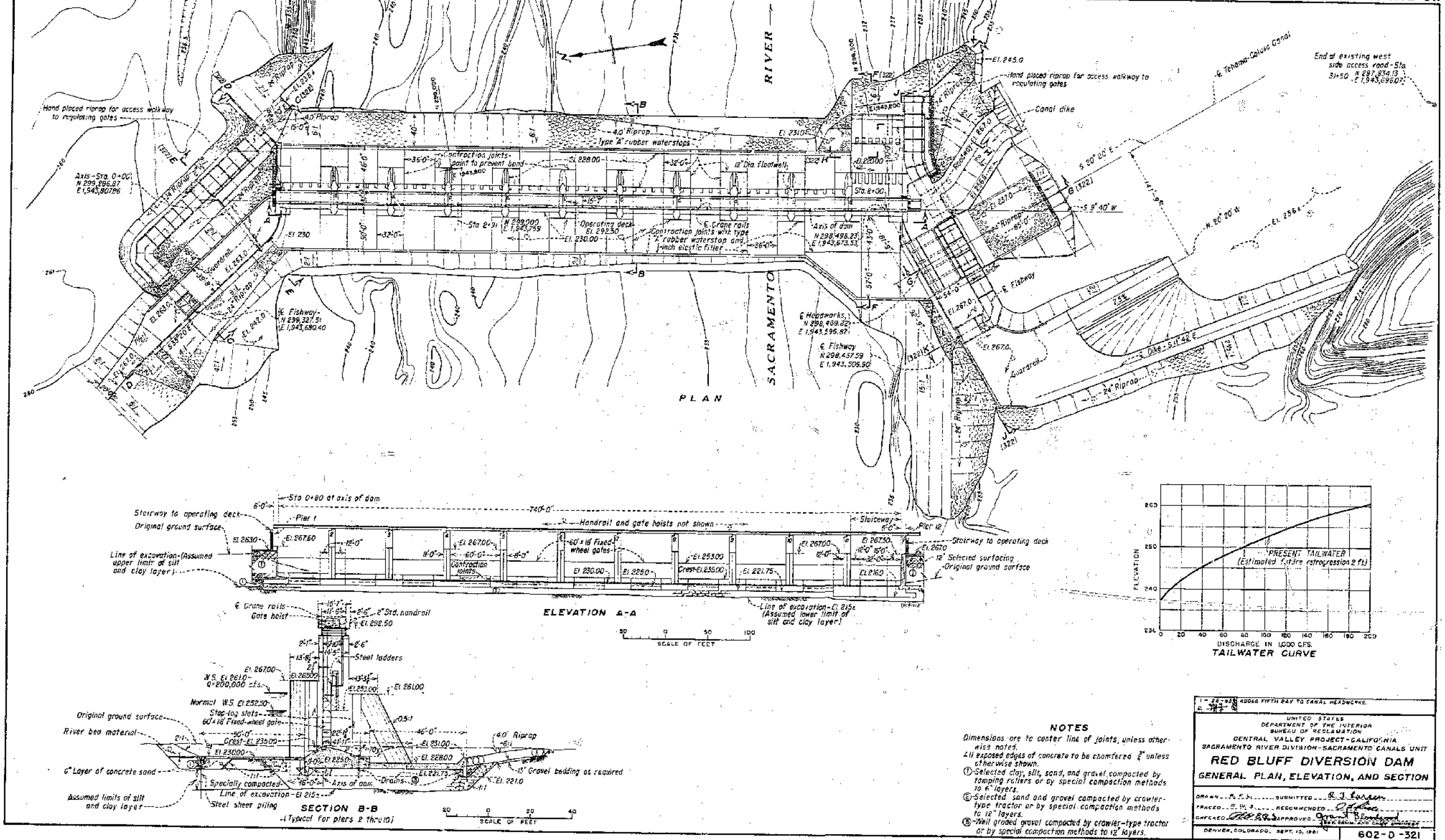
Table III

FREELY SUSPENDED MODE DATA
Unsubmerged flow
Maximum Downpull Determination

	Model			Prototype		
Run. number	H_1* (ft)	b* (in.)	Down-pull (lb)	H_1* (ft)	b* (in.)	Down-pull (lb)
1	0.97	1/32	0.8	18.0	0.581	5,150
1	0.97	5/32	1.1	18.0	2.90	7,080
1	0.97	9/32	2.0	18.0	5.23	12,900
1	0.97	13/32	1.25	18.0	7.55	8,040
2	0.97	1/32	1.0	18.0	0.581	6,435
2	0.97	5/32	1.4	18.0	2.90	9,010
2	0.97	9/32	2.0	18.0	5.23	12,900
2	0.97	13/32	1.5	18.0	7.55	9,650

*See Figure 11 for symbol definitions.


Redding
Millville
Viola
Bear Creek
Igo
Ono
Oak
Anderson
Gas Point
Manton
Battle Creek
Cottonwood Creek
Cottonwood
Paynes Creek
Dales
Rosewood
SEVEN-MILE-PAYNES CREEK AREA ROCK SOURCE
ANTELOPE CREEK CANYON ROCK SOURCE
Antelope Creek
Hooker Cr.
Blue Tent Cr.
Pine Creek
Red Bluff
RED BLUFF DIVERSION DAM
Reed Cr.
Redbank Cr.
SACRAMENTO RIVER
Proberta
Mill Creek
Elder Creek
Tehama
Los Molinos
Deer Creek
Flournoy
Corning
Vina
Cohasset
Thomes Creek
Paskenta
Jewett Creek
Cana
Rock Creek
Nord
Newville
Chico
Orland
Hamilton City
S H A S T A
T E H A M A
G L E N N
B U T T E
SYMBOLS
U.S. AND STATE HIGHWAYS
OTHER ROADS
SCALE OF MILES
KEY MAP
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CENTRAL VALLEY PROJECT - CALIFORNIA
SACRAMENTO RIVER DIV.-SACRAMENTO CANALS UNIT
RED BLUFF DIVERSION DAM
LOCATION MAP
DENVER, COLORADO, SEPT. 18, 1961
602-D-319
FORMERLY DWG. 602-D-3


PLAN
RIVER
SACRAMENTO
ELEVATION A-A
SECTION B-B
(Typical for piers 2 thru 10)
TAILWATER CURVE
DISCHARGE IN 1,000 C.F.S.
ELEVATION
PRESENT TAILWATER
(Estimated future retrogression 2 ft)
NOTES
Dimensions are to center line of joints, unless otherwise noted.
All exposed edges of concrete to be chamfered 3/4" unless otherwise shown.
① Selected clay, silt, sand, and gravel compacted by tamping rollers or by special compaction methods to 6" layers.
② Selected sand and gravel compacted by crawler-type tractor or by special compaction methods to 12" layers.
③ Well graded gravel compacted by crawler-type tractor or by special compaction methods to 12" layers.
ADDED FIFTH BAY TO CANAL HEADWORKS.
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CENTRAL VALLEY PROJECT-CALIFORNIA
SACRAMENTO RIVER DIVISION-SACRAMENTO CANALS UNIT
RED BLUFF DIVERSION DAM
GENERAL PLAN, ELEVATION, AND SECTION
DENVER, COLORADO, SEPT. 15, 1961
602-D-321
FORMERLY DWG. 602-D-6

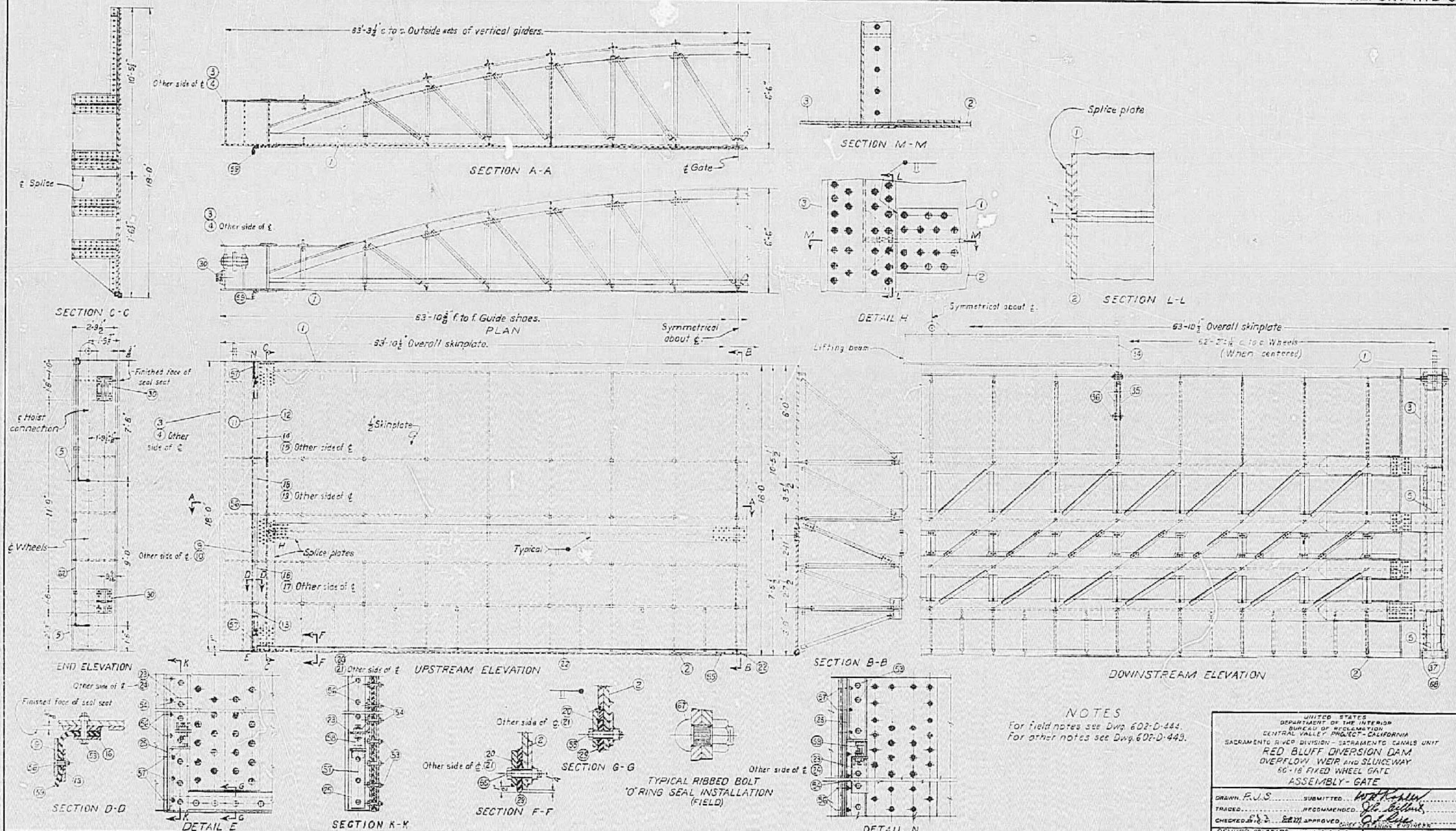
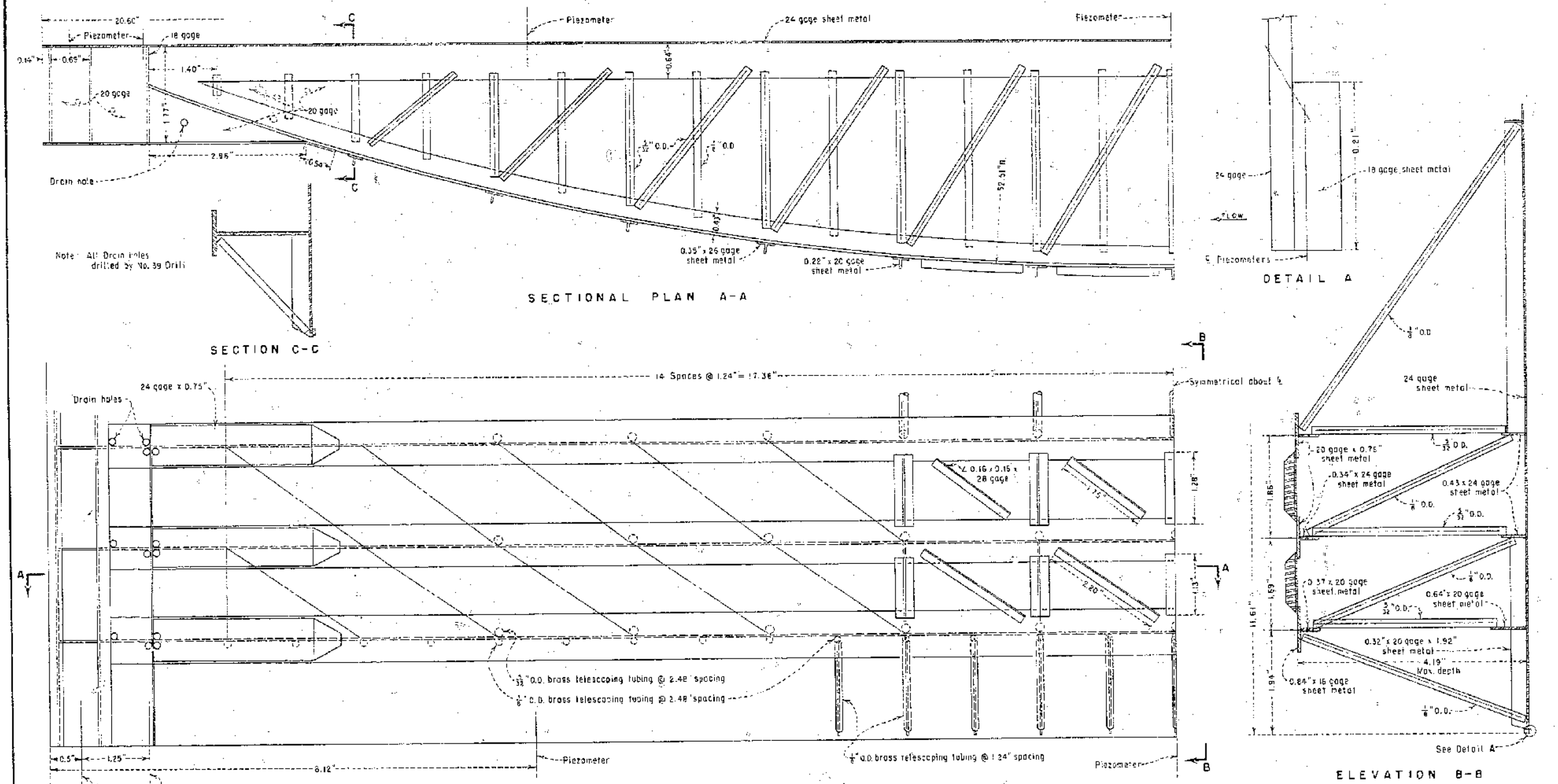
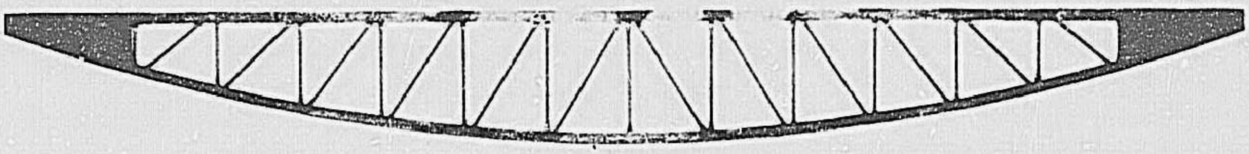

SECTION A-A
PLAN
SECTION M-M
DETAIL H
SECTION L-L
Splice plate
SECTION C-C
END ELEVATION
UPSTREAM ELEVATION
SECTION B-B
DOWNSTREAM ELEVATION
SECTION D-D
DETAIL E
SECTION K-K
SECTION F-F
SECTION G-G
TYPICAL RIBBED BOLT
"O" RING SEAL INSTALLATION
(FIELD)
DETAIL N
NOTES
For field notes see Dwg. 602-D-444.
For other notes see Dwg. 602-D-449.
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CENTRAL VALLEY PROJECT-CALIFORNIA
SACRAMENTO RIVER DIVISION - SACRAMENTO CANALS UNIT
RED BLUFF DIVERSION DAM
OVERFLOW WEIR AND SLUICEWAY
60'-18' FIXED WHEEL GATE
ASSEMBLY-GATE
DENVER, COLORADO
602-D-446

FIGURE 4
REPORT HYD. 511

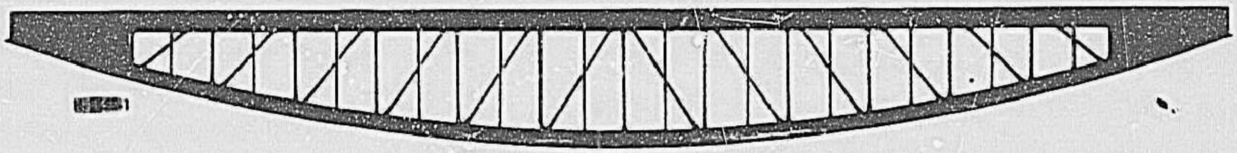


RED BLUFF DIVERSION GATE
DOWNPULL STUDIES
MODEL DRAWING OF 60 FOOT BY 18 FOOT FIXED WHEEL GATE
1:18.6 SCALE MODEL

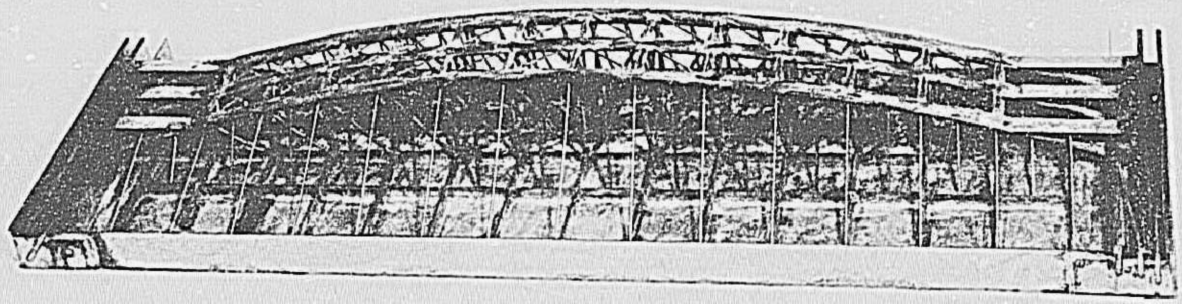
Figure 5
Report Hyd-511



A. Upper bow truss



B. Lower bow truss

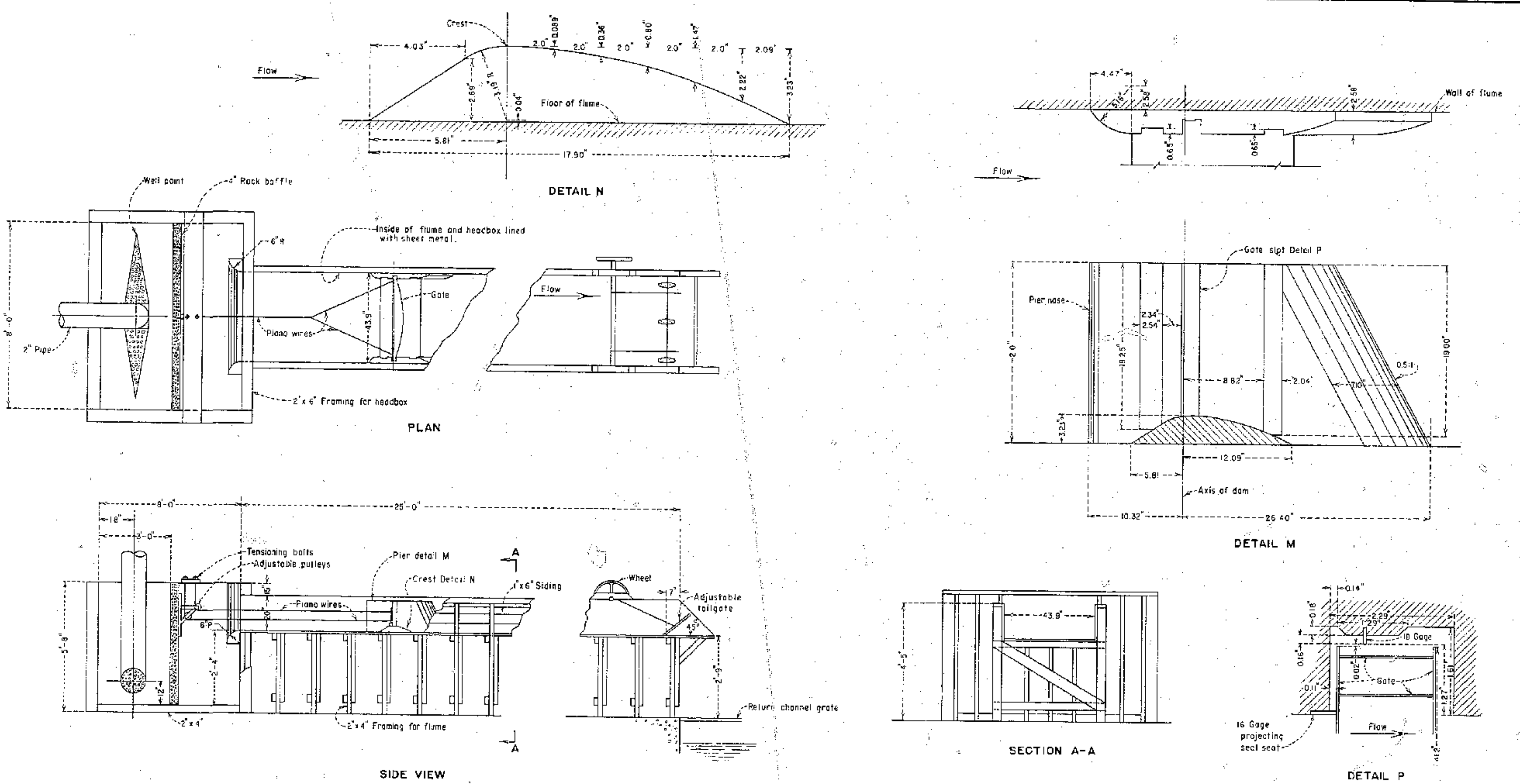


C. Assembled gate viewed from top rear

D. Assembled gate viewed from bottom

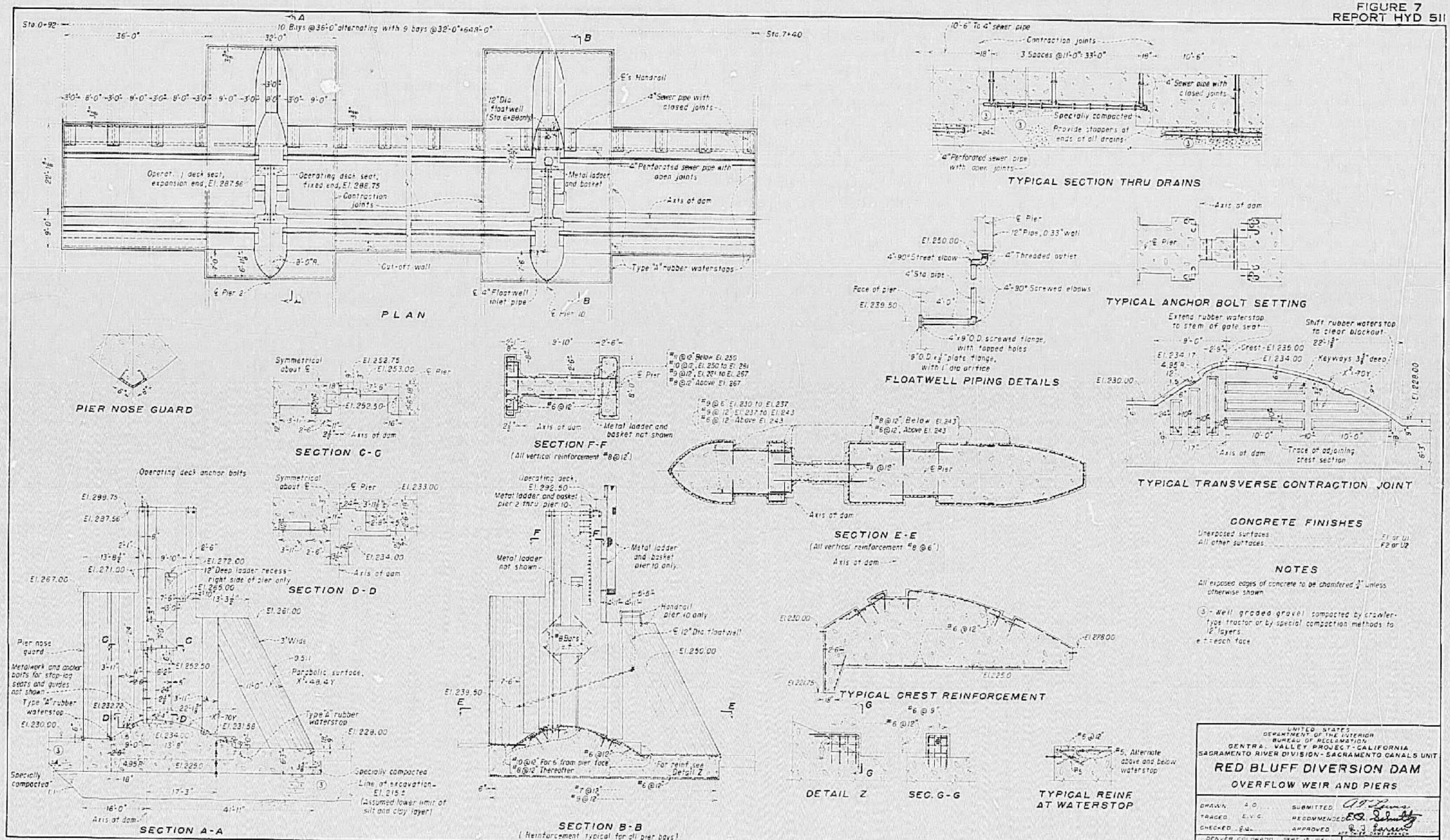
RED BLUFF DIVERSION GATE
DOWNPULL STUDIES

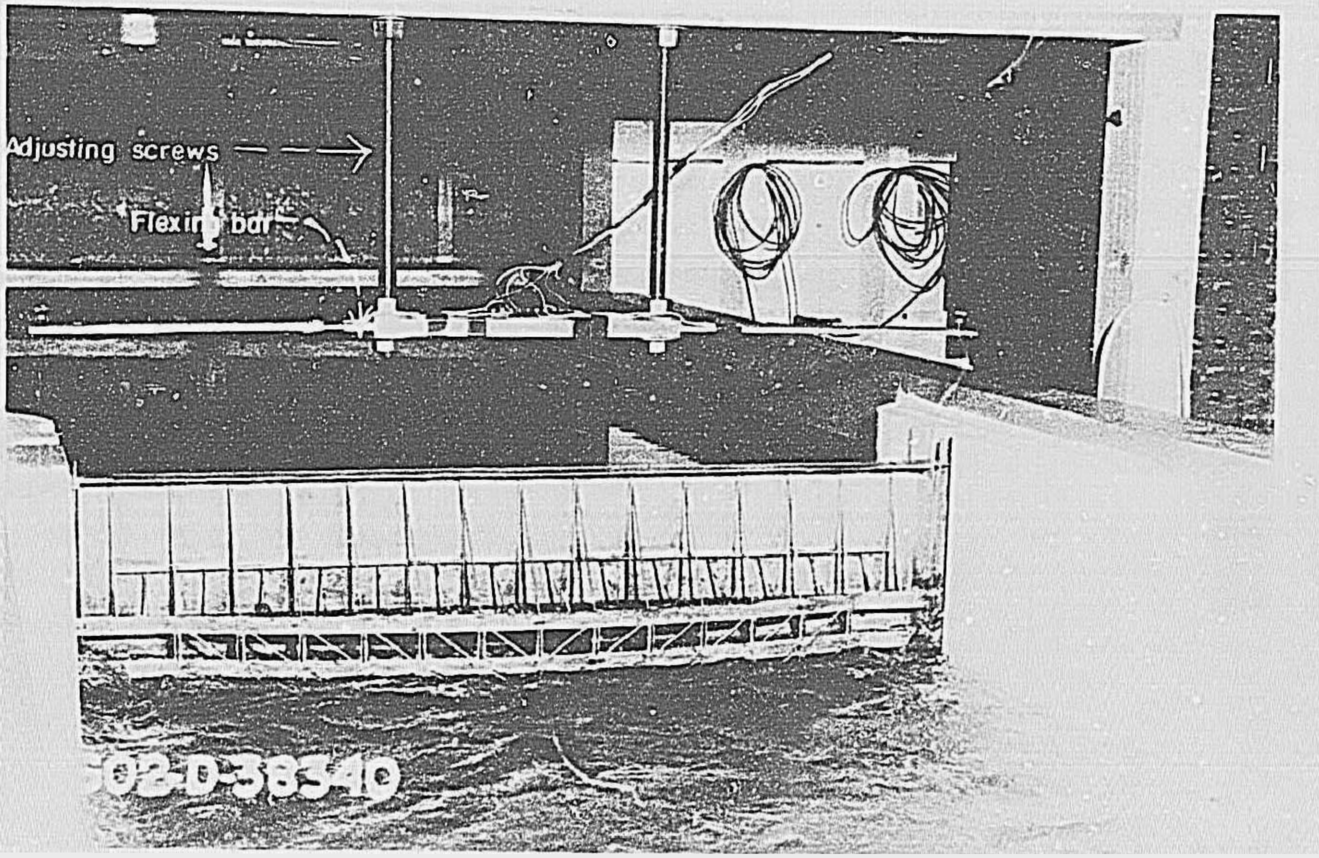
Model of the Open Truss Fixed-wheel Gate
1:18.6 Model



RED BLUFF DIVERSION GATE
DOWNPULL STUDIES
MODEL ARRANGEMENT FOR STUDY OF 60 FOOT BY 18 FOOT FIXED WHEEL GATE
1:18.6 SCALE MODEL

657

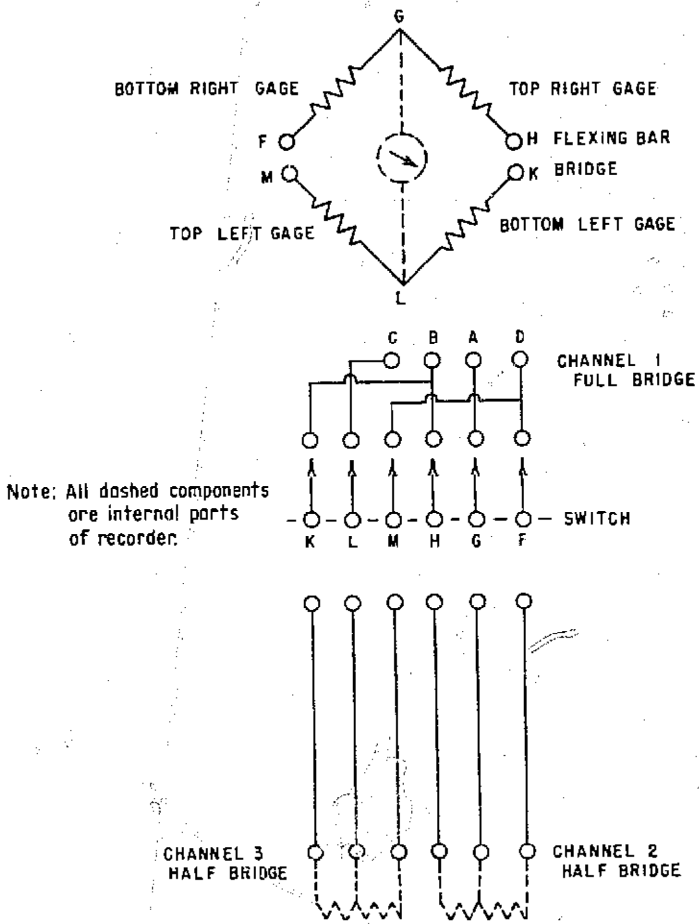

PLAN
PIER NOSE GUARD
SECTION C-C
SECTION D-D
SECTION A-A
SECTION F-F
(All vertical reinforcement #8 @ 12")
SECTION B-B
(Reinforcement typical for all pier bays)
SECTION E-E
(All vertical reinforcement #8 @ 6")
TYPICAL SECTION THRU DRAINS
FLOATWELL PIPING DETAILS
TYPICAL ANCHOR BOLT SETTING
TYPICAL TRANSVERSE CONTRACTION JOINT
TYPICAL CREST REINFORCEMENT
DETAIL Z
SEC. G-G
TYPICAL REINF. AT WATERSTOP
CONCRETE FINISHES
Unexposed surfaces F1 or U1
All other surfaces F2 or U2
NOTES
All exposed edges of concrete to be chamfered 3/4" unless otherwise shown
(3) - Well graded gravel compacted by crawler-type tractor or by special compaction methods to 12" layers.
e.f. = each face
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CENTRAL VALLEY PROJECT-CALIFORNIA
SACRAMENTO RIVER DIVISION-SACRAMENTO CANALS UNIT
RED BLUFF DIVERSION DAM
OVERFLOW WEIR AND PIERS
DENVER, COLORADO, SEPT. 15, 1961
602-D-328
FORMERLY DWG. 602-D-8



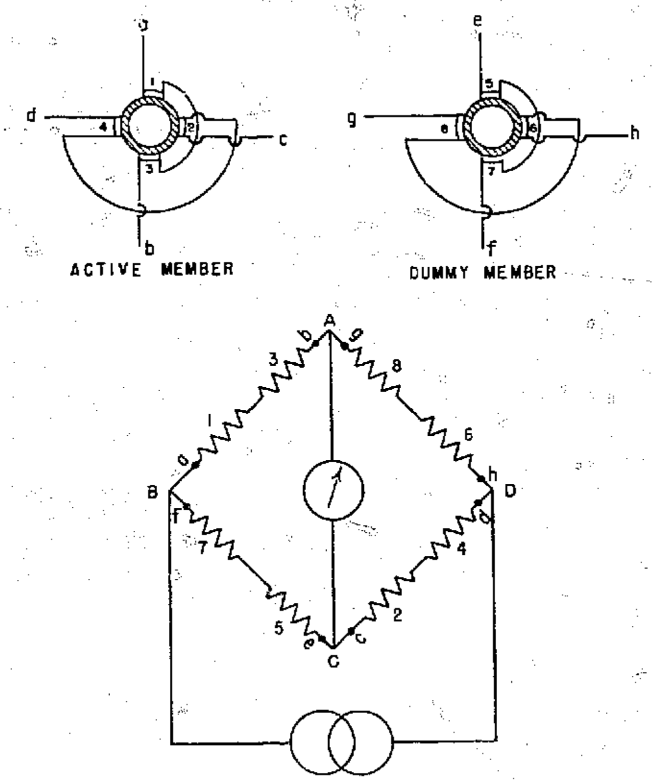
Flexing bar installed in model

RED BLUFF DIVERSION GATE
DOWNPULL STUDIES

Vertical Suspension Used for Model Weighing Technique
1:18.6 Scale Model



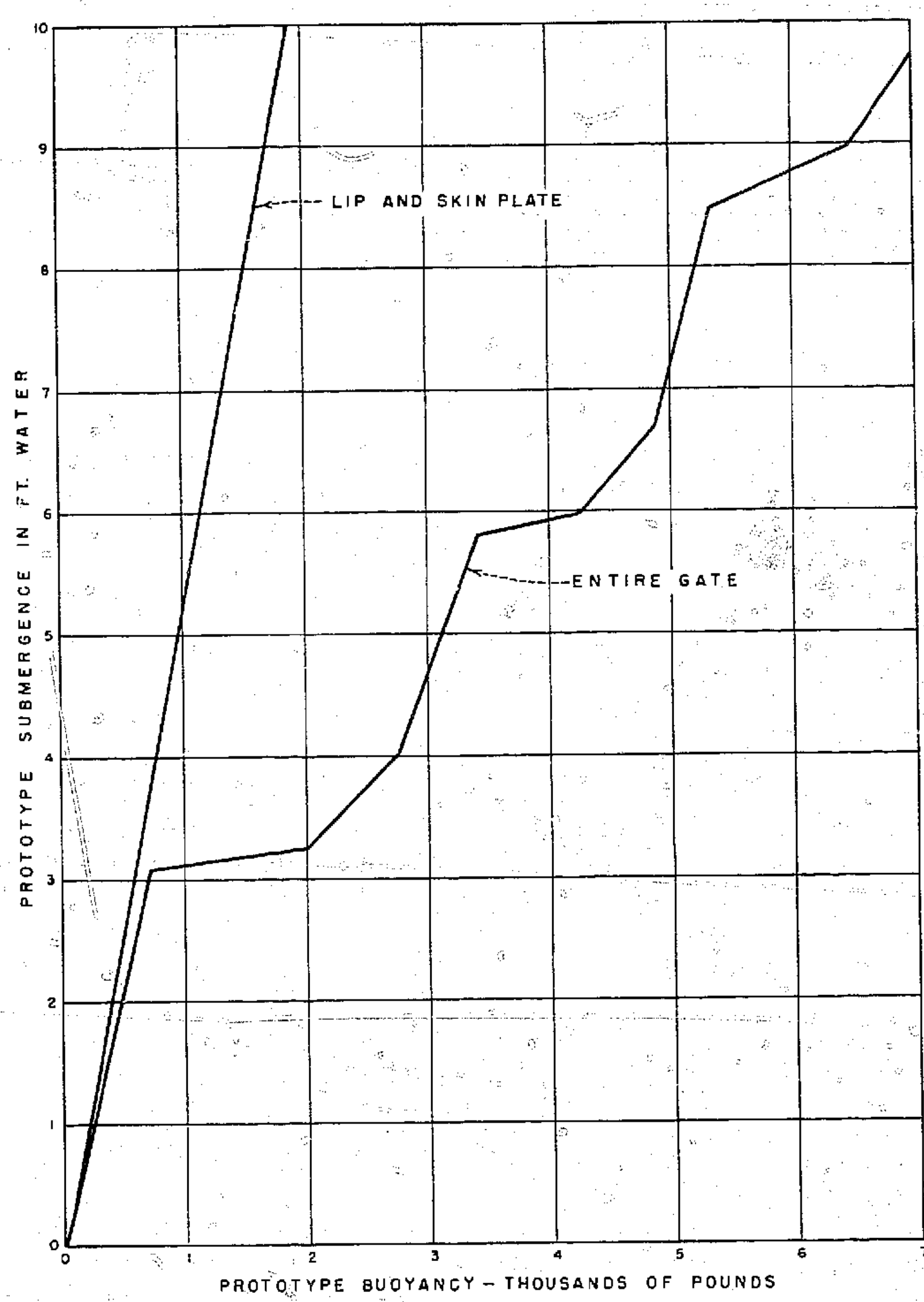
A. CIRCUITS FOR MEASURING VERTICAL FORCES USING FLEXING BAR



B. CIRCUITS FOR MEASURING HORIZONTAL FORCES IN HARNESS USING TUBING

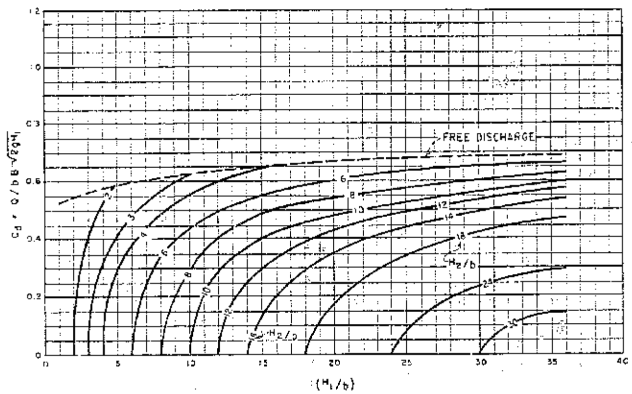
RED BLUFF DIVERSION GATE
DOWNFULL STUDIES
INSTRUMENT CIRCUITS FOR FORCE MEASUREMENTS ON MODEL GATE
1:18.6 SCALE MODEL

FIGURE 9
REPORT HYD. 511

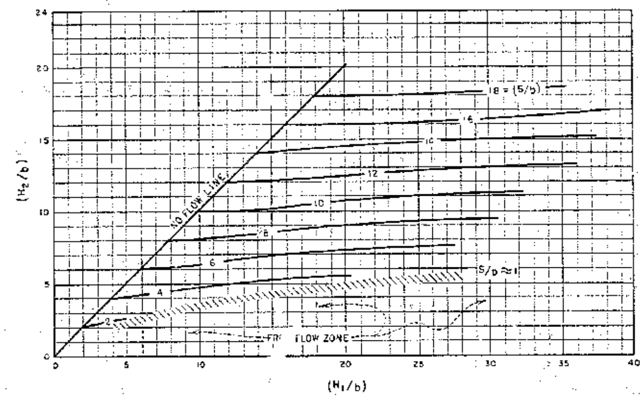


RED BLUFF DIVERSION GATE
DOWNPULL STUDIES
BOUYANT FORCE ON PROTOTYPE GATE
DATA FROM 1:18.6 SCALE MODEL

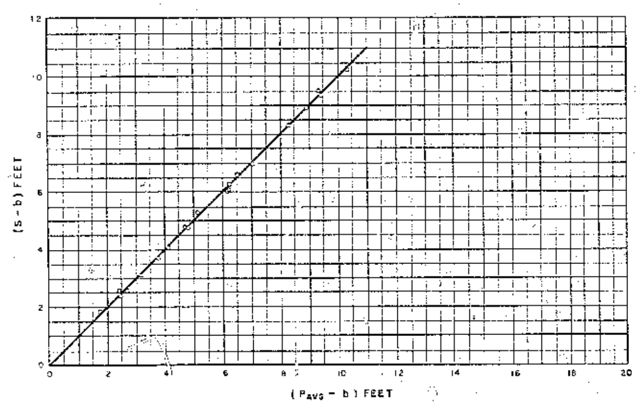
FIGURE 11



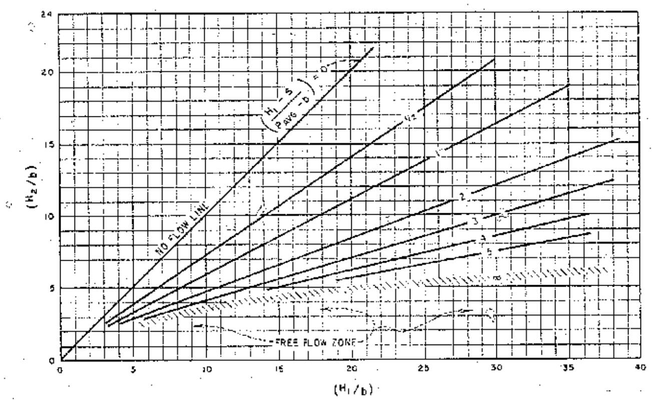
A. COEFFICIENT OF DISCHARGE



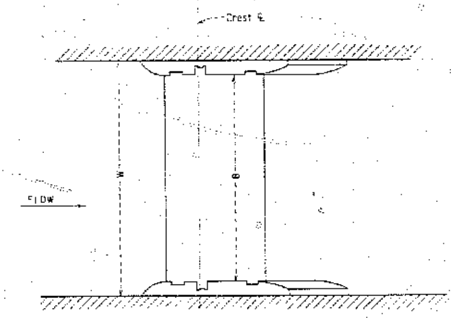
B. SUBMERGENCE CHARACTERISTICS



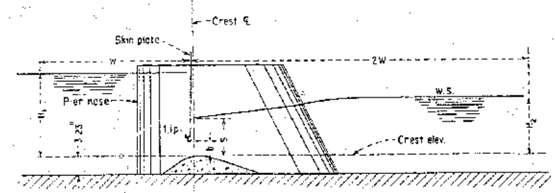
C. SUBMERGENCE HEAD VERSUS LIP PRESSURE HEAD



D. PRESSURE HEAD COEFFICIENT OF GATE LIP



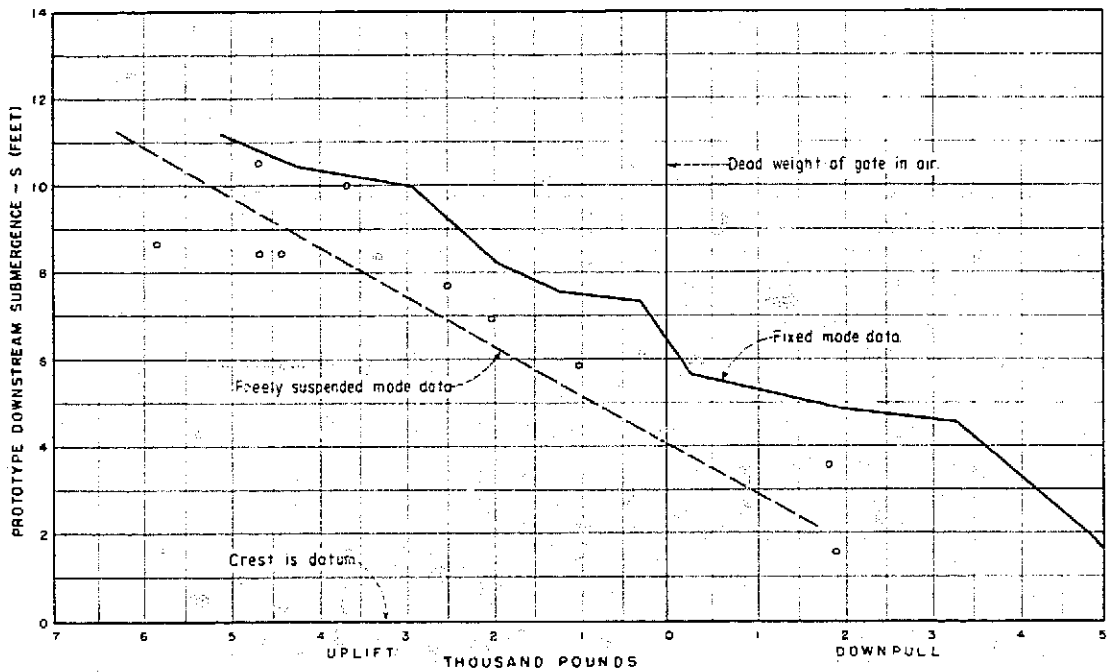
PLAN



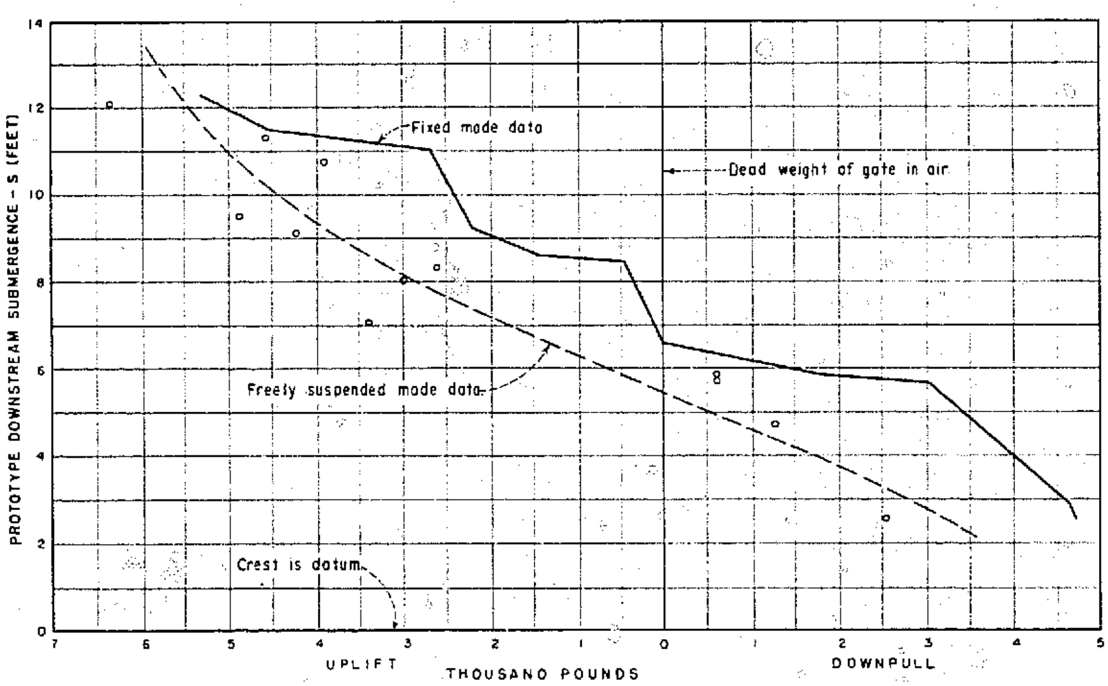
PROFILE

DEFINITION SKETCH

RED BLUFF DIVERSION GATE
DOWNPULL STUDIES
HYDRAULIC PROPERTIES OF GATES
DATA FROM 1:18.5 SCALE MODEL



A. VERTICAL FORCE FOR GATE OPENING OF 1.65 FEET

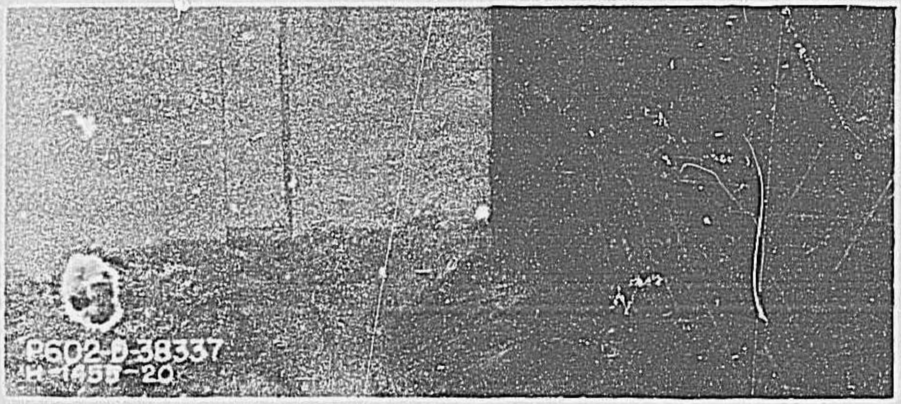


B. VERTICAL FORCE FOR GATE OPENING OF 2.58 FEET

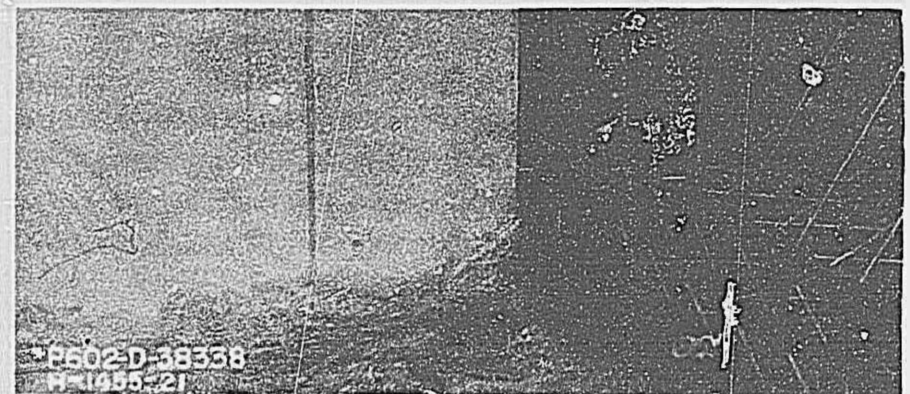
RED BLUFF DIVERSION GATE
DOWNPULL STUDIES
VERTICAL FORCES ON GATE AT 18 FOOT HEAD
FOR TWO GATE OPENINGS

DATA FROM 1:18.6 SCALE MODEL

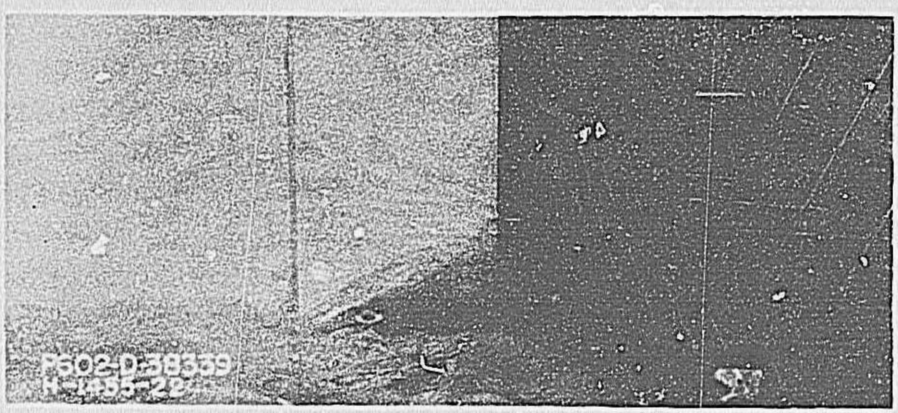
657



A. Gate floating in slot



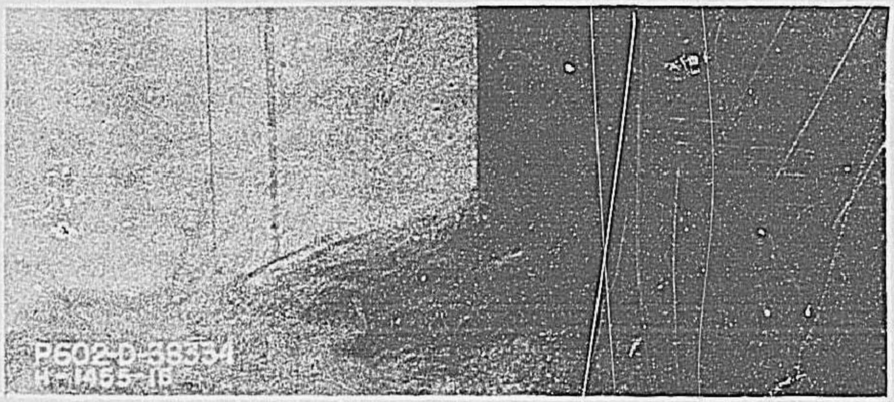
B. Gate fixed against upstream slot seal projection



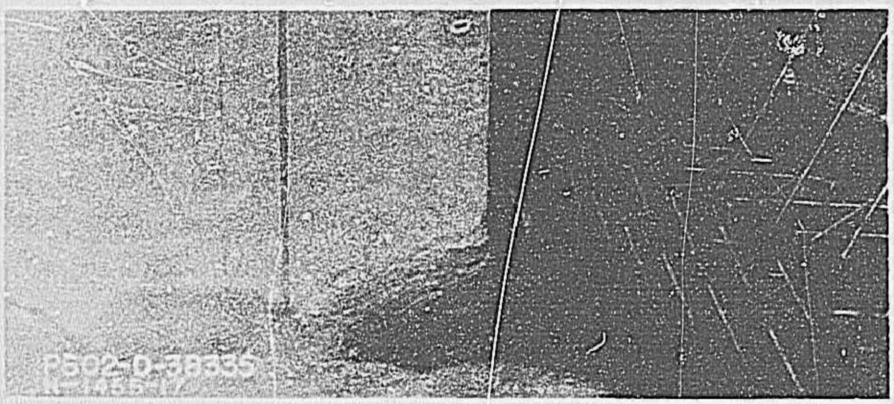
C. Gate fixed and completely sealed on upstream face with modeling clay

RED BLUFF DIVERSION DAM
DOWNPULL STUDIES

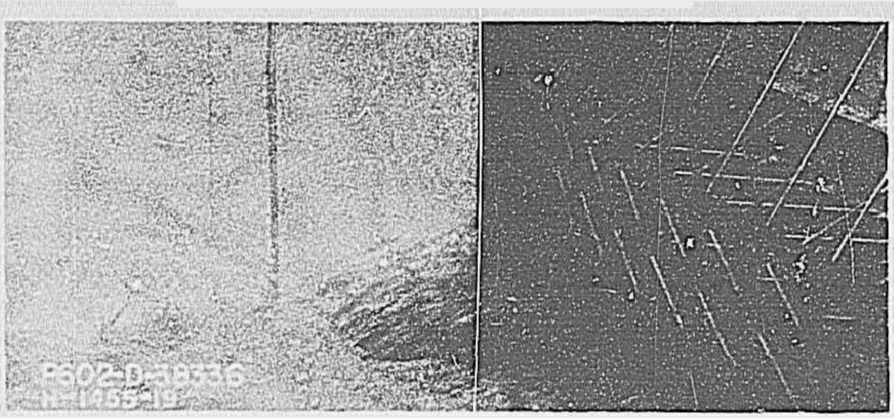
Flow Conditions at Slot for Different Methods of Suspending and Sealing Model Gate
Gate Opening (b) = 1.2 Feet
Head (H_1) = 18 Feet
1:18.6 Scale Model



A. Gate floating in slot



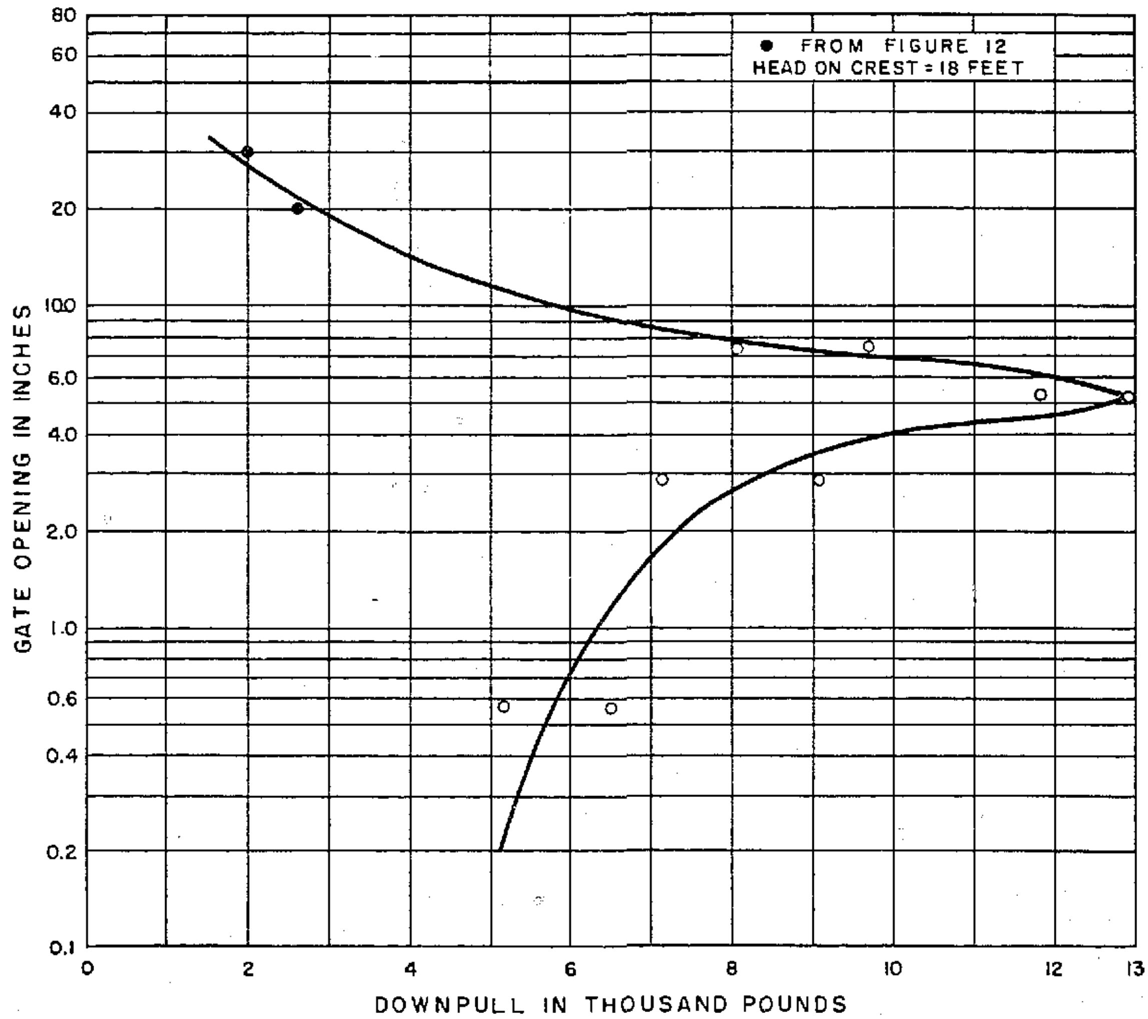
B. Gate fixed against upstream slot seal projection



C. Gate fixed and completely sealed on upstream face with modeling clay

RED BLUFF DIVERSION GATE
DOWNPULL STUDIES

Flow Conditions at Slot for Different Methods of Suspending and Sealing Model Gate
Gate Opening (b) = 2.6 Feet
Head (H_1) = 18 Feet
1:18.6 Scale Model



RED BLUFF DIVERSION GATE

DOWNPULL STUDIES

DOWNPULL FORCE FOR FREE DISCHARGE

DATA FROM 1:18.6 SCALE MODEL

GPO 834098